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SECOND QUARTERLY PROGRESS REPORT

UPDATED OPTICAL READ/WRITE MEMORY SYSTEM COMPONENTS

PERIOD: 1 NOVEMBER 1973 – 31 JANUARY 1974

NASA CONTRACT NAS 8-26672
REQUEST NO. 1-3-40-02885 (1F)
DRL NO. 237
DRL LINE ITEM NO. 1

FEBRUARY 1974

Prepared For:
GEORGE C. MARSHALL SPACE FLIGHT CENTER
MARSHALL SPACE FLIGHT CENTER, ALABAMA 35812

By:
ELECTRO-OPTICS OPERATION

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FORWARD

This report was prepared by the Electro-Optics Operation of Radiation, A Division of Harris Intertype Corporation, under Contract NAS 8-26672 with the NASA-Marshall Space Flight Center, Huntsville, Alabama. This effort is monitored by E. J. Reinbolt, Deputy of the Technology Division, Astrionics Laboratory, NASA/MSFC, who is the Contracting Officer's Technical Representative.

The Program Manager for this effort is A. J. Cornish, who reports to R. M. Montgomery, Director, Engineering and Development, Electro-Optics Operation. Other contributors to this report are C. R. Burr, M. D. Drake, H. N. Roberts, W. A. Robson, E. N. Tompkins and F. B. Rotz.

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INTRODUCTION AND SUMMARY

1.1 Objectives of the Contract

The Electro-Optics Operation of Radiation, a Division of Harris Intertype, under Contract NASA 8-26672, is continuing the development of a 10^{10} to 10^{12} bit memory system. The present effort consists of a study and fabrication of a holographic storage array and a block data composer of increased capacity. Under the contract the NASA test bed is continuously modified to accept and demonstrate the improved devices.

1.2 Summary of Work Performed During the Second Quarter

A survey of the building blocks of the electro-optic read/write system was made. This incorporates new information obtained in this and other studies. Critical areas and alternate paths are discussed. The latest PLZT block data composer is analyzed. Stricter controls in the production and fabrication of PLZT are implied by the performance of the BDC. A reverse charge before erase has eliminated several problems observed in the parallel plane charging process for photoconductor-thermoplastic hologram storage.

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SYSTEM CONSIDERATIONS

Introduction

Further investigations of system configurations for a 10^{10} to 10^{12} bit read/write memory have begun. New system concepts are to be considered, including the addition of mechanisms for translating the recording material into and out of the recording position. Continuing objectives will be to minimize the requirements for moving parts and to utilize, where necessary, the simplest and most reliable mechanisms. The emphasis in these investigations is to remain largely on electronic and electro-optic techniques for performing the various system functions *in situ*.

The basic building blocks for these systems are reviewed briefly. For each of these building blocks, a number of approaches and important considerations are identified. The purpose of this discussion is to provide a framework from which more specific and detailed designs of subsequent systems can be drawn.

During the present program it may be possible to implement a simple mechanism for increasing the accessible number of hologram recording positions. A discussion of the changes in the present feasibility system which might be made to provide this added feature is included.

2.1 Review of System Building Blocks

Several basic building blocks are common to nearly all holographic read/write memory systems. The more important ones are outlines below. Representative alternative approaches are denoted by the symbol *. Important design aspects which must be considered are denoted by the symbol †.

Hologram Array Translation Mechanism

* None (no moving parts approach with beam deflection only for access)
* Rotating disc
* Reel-to-reel cassette
* X or X-Y translating slide
† One-or two-dimensional accessing
† Random access time
† Motion of photoplastic during record and readout
† Positioning accuracy (servo requirements)
† Memory capacity (total accessible area)
† Start and stop transients
† Reliability

Beam Deflector

* None (two-dimensional mechanical translation of hologram array)
* Acousto-optic
* Electro-optic
* Moving mirror (e.g., galvanometer)
† One- or two-dimensional deflection
† Random access time
† Resolution (e.g., time-bandwidth for the acousto-optic approach)

Signal Beam Transform Optics (BDC-to-PDA)

- * Off-the-shelf (possible with no beam deflection)
- * Special design
- † Space-bandwidth required in each dimension
- † Magnification
- † Size and data capacity of each hologram
- † Apertures and focal powers

Input Device (Block Data Composer)

- * Electro-optic, including PLZT
- * Acousto-optic
- † One- or two-dimensional format
- † Data rates
- † Modulating element dimensions
- † Data motion (acousto-optic)
- † Optical efficiency

Output Device (Photodetector Array)

- * Westinghouse two-dimensional photodiode array
- * Discrete photodiodes with fiber optic signal distribution from the image plane
- * Reticon self-scanned photodiode arrays
- * Fairchild charge-coupled photodetecting arrays
- † One- or two-dimensional format
- † Data rates
- † Detecting element dimensions
- † Sensitivity

Recording Material

* Photoplastic
† Charging
† Heating
† Lifetime
† Erasure (by position, by row, by sector, or entire memory)
† Compatability with various accessing approaches
† Wavelength sensitization

Laser

* Argon-ion (488.0 nm or 514.5 nm)
* Helium-neon (632.8 nm)
* Helium-cadmium (441.6 nm)
* Krypton-ion (530.9 nm or 647.1 nm)
† Average power
† Pulse length and duty
† Internal or external modulation
† Size, input power, utilities (water or air)
† Stability

Other System Considerations

† Overall size
† Power and other utility requirements
† Control of all components and functions
† Reference/Readout beam optics
† Bit error rates (flag sensitive components and parameters)
† Tradeoffs related to adding or deleting memory capacity

In the next section each of these building blocks is discussed briefly. Certain of the more important tradeoffs to be investigated subsequently in more detail are indicated.

2.2 Hologram Array Accessing

To access any one hologram recording position will in general require activation of both the translation mechanism and the beam deflector. The two extreme cases of hologram accessing are:

1. Two dimensional beam deflection, as in the present feasibility system, with no moving parts;
2. Two-dimensional mechanical translation of the hologram array with no beam deflection.

One important tradeoff to consider between these extremes is the design of the transform lenses. The two-dimensional space-bandwidth product for this lens system for the "no moving parts" approach is,

$$(SB)_1 = \beta Q_T \qquad (1)$$

where β is a parameter which accounts for the bit resolvability at the PDA, for guard bands, and for matching a square BDC and HA to round lenses ($\beta \geq 3$); Q_T is the total capacity of the memory. For the other extreme,

$$(SB)_2 = \beta \frac{Q_T}{N_T} \qquad (2)$$

where N_T is the total number of hologram recording positions accessed by the translation mechanism. Clearly the lens design is significantly easier with no beam deflection.

Accessing approaches which incorporate both beam deflection and hologram translation can be conceived which require a lens design which is a compromise between these two extremes. For example, an approach similar to the present feasibility system could be used with the addition of an X-Y hologram array translator. The recording plane could be organized into smaller square sectors. The hologram translation mechanism would translate a selected sector into the record/readout position. A low-resolution beam deflector would then provide access to each position within a sector. The space-bandwidth requirement on the transform lenses for such a case is,

$$(SB)_3 = \beta \frac{Q_T}{N_S} = \beta Q_S \tag{3}$$

where N_S is the total number of sectors and Q_S is the capacity of each sector. For this particular approach the BDC and PDA design criteria are identical to those presented in the most recent Final Report. The AOBD and transform lens designs are considerably relaxed from the "no moving parts" case.

Other configurations can be conceived. A particularly interesting one involves a one-dimensional BDC, one-dimensional beam deflection, and a cassette-type hologram translation mechanism (a tape transport). Such approaches require more consideration.

2.3 Input and Output Devices

A major consideration for the input and output devices (the BDC and the PDA) is the choice between one- and two-dimensional formats.

One-dimensional acousto-optic and electro-optic BDC's are presently feasible. There is no data motion in either of these, although a fixed frequency shift must be imparted to the reference beam for the acousto-optic BDC. Input data rates well over 100 Mb/s can be provided with one-dimensional acousto-optic BDC's.

Similarly, one-dimensional PDA's can be implemented in several ways. Linear self-scanned photodiode arrays have been used successfully in the HRMR system. Discrete photodetectors with a fiber optic signal distributor from an image plane of the reconstructed data are being implemented for the Wideband Holographic Recorder for RADC.(1) A linear charge-coupled photodetecting device with 500 elements has been successfully tested in our facility. One-dimensional PDA's appear to be quite feasible for data rates to at least 40 Mb/s.

These facts concerning one-dimensional BDC's and PDA's indicate that careful consideration must be given to holographic read/write memory systems which can take advantage of these rather well-developed technologies.

Two-dimensional acousto-optic BDC's are well-developed also, but the data moves in these devices. Also, the frequency shifts on the signal beam can only be partially compensated. Such a BDC can only be used in conjunction with a laser which provides short intense pulses to record holograms. The mode-locked and cavity-dumped laser approach can provide short enough pulses. The per pulse energy requirements must be investigated in detail for systems configured with these devices to determine feasibility.

2.4 Recording Material

At present, the photoplastic materials appear to be the only reasonable choice for the read/write memory.

A significant portion of any subsequent system investigation activity will be to determine the compatability of photoplastics with the various hologram accessing formats. Methods for properly charging and heating each recording position as it is accessed for recording or erasure must be provided. In certain configurations it will be impossible to develop or erase holograms individually. The question of row, sector, or full memory erasure prior to reuse must be investigated in relation to the user requirements.

If a cassette tape approach is found to have special and desirable advantages, the photoplastic will have to be coated onto a flexible substrate. The effects on photoplastic performance of a large number of wind-rewind cycles must be determined before such a system can be seriously considered.

With the slide approaches, the photoplastic is never wound on itself or grossly flexed. However, techniques for uniformly coating the active areas for such formats would have to be developed, along with charging and heating techniques, if one of these approaches were to be selected.

2.5 Laser

With photoplastics used as a thin phase recording material, only one laser wavelength is required. The choice of the wavelength is likely to be made by trading off PDA sensitivity, diffraction limited resolution, and average power requirements. The question of internal versus external modulation must be considered after a system is defined to determine which is the most efficient method. Pulse widths, duty cycles, and per pulse energy requirements will be the primary parameters to consider.

2.6 Other System Considerations

Once the control requirements for all system components are defined, a controller can be specified without difficulty.

The reference/readout beam optics are not expected to present any unusual requirements for any conceivable system.

Those system components and parameters to which the output signal-to-noise ratio (and, thus, bit error rate) is most sensitive must be flagged for each system considered. For example, electrical crosstalk in the BDC must be controlled carefully. Also, any constraints on photoplastic parameters (such as offset angle) for maximizing diffraction efficiency and minimizing SNR must be factored into the system layout.

For each type of system considered, it would be useful to indicate the tradeoffs which must be made in adding or deleting memory capacity. Some systems may be more amenable to increased capacities than others; this parameter could affect the selection of a system configuration.

2.7 Modifications to Present Feasibility System

There is a simple modification which can be made to the present feasibility system which permits the existing components to be fully utilized while the net memory capacity is increased. The fixed hologram array can be replaced by a mechanically controlled sliding fixture to which several similar hologram arrays are attached. These adjacent similar arrays (or sectors) will be translated by the sliding fixture into the record/readout position by a command from the controller. Such a modification will provide experience with simple mechanisms for translating the hologram array and with techniques for charging, heating, and erasing a movable array.

The impact on the overall resources of the program of implementing such a modification must be assessed. It is not clear that such a modification is within the scope of this program.

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BLOCK DATA COMPOSER

The block data composer (BDC) converts the incoming electrical data stream to an optical form through amplitude and/or phase modulation of the signal beam in the holographic memory system. The signal beam is modulated by a planar matrix of electro-optic elements whose indices of refraction are changed by the application of electrical pulses. Two types of matrix BDC's have been investigated: 1) a square matrix array of elements that is scanned line by line (non-memory)[1] and 2) a square matrix array of elements with memory. The first type uses linear or quadratic electro-optic materials and has the potential of greater depth of modulation (higher contrast ratio) but requires multiple hologram exposures to record the data from the full matrix. The second type acts as a buffer memory. The data is entered line by line and is retained. A single exposure of the data array is used in recording the hologram.

We are currently investigating the memory type of BDC with ceramic PLZT 7/65/35 as the electro-optic memory material. This material consists of $PbZrO_3$ and $PbTiO_3$ in a ratio of 65% to 35% by weight, doped with 7 atomic % of La on the Pb sites.[2] The PLZT currently being used is of chemically co-precipitated, oxygen hot-pressed manufacture; materials used previously were made from the mixed oxides.

Other electro-optic materials such as single crystal $Gd_2(MoO_4)_3$[3] and CdS[4] can also be used in the memory type BDC. The principle drawbacks to these materials are slower speed and fabrication difficulties. However, the progress of such materials is being monitored since they are possible alternatives to the use of PLZT.

3.1 Fabrication of PLZT Block Data Composers

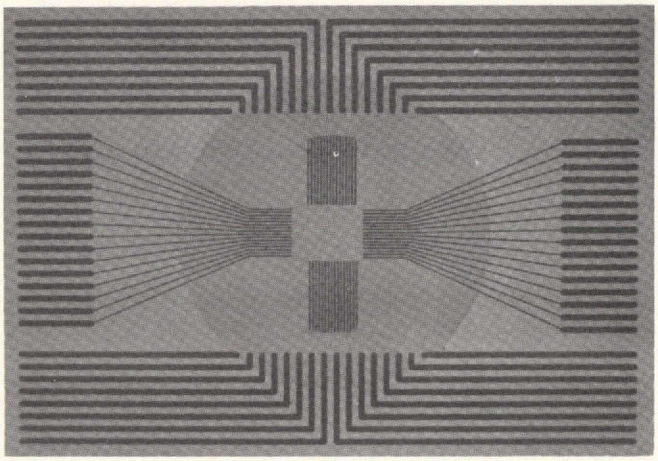
The work of the past period has centered on the fabrication of 32 x 32 element Block Data Composers with element dimensions and spacings changed to be compatible with those of the photo-detector array. The elements now have a 127 x 127 μm active area spaced on 254 μm centers. The electrode contacting lines on the plexiglas substrates also had to be altered in position, width and thickness. New photomasks were made for the altered substrate patterns as well as for the electrode lines on the PLZT.

The transparent electrodes on the PLZT are formed from thin sputtered films of indium oxide doped with 9% tin oxide (ITO). The sheet resistance of these sputtered films has consistently been held to below 30 Ω/□ in the past period and recently we have been able to keep it below 15 Ω/□ . The electrode lines are defined by photo-resist methods. A problem found in several earlier BDC's with ITO electrodes was high resistance leakage paths between the electrodes due to incomplete etching of the ITO. We have tried several different types of photo-resist to find one that would not be dissolved by the acid etchant before the ITO was completely etched. Shipley AZ-111 photo-resist with a long bake before the etching has yielded satisfactory results. However, the great amount of handling necessary in the photo-resist processes has caused a higher rate of breakage of the PLZT.

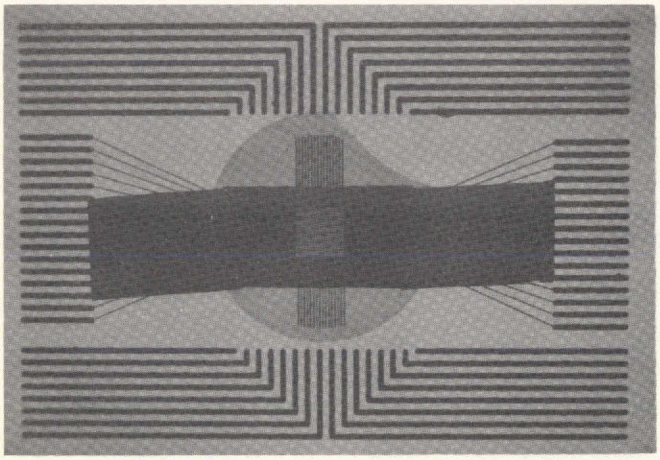
The bonding of connecting wires directly to the top ITO electrodes of the BDC has not been successful, and for the present, the top electrodes will continue to be hand soldered.

In the past period, 8 pieces of PLZT have been electroded and thermocompression bonded with epoxy to substrates. Of these, 6 were wired for testing, the other two having cracked in the press from polishing scratches. Two of the completed 32 x 32 element BDC's are shown in Figure 3-1. All of the PLZT used in the 6 finished devices with the exception of one piece, was material that had been received and/or polished in the previous periods.

We received unpolished discs of PLZT 7/65/35 from Sandia and Opto-Ceram at the beginning of the period and from Honeywell late in the period but we were not able to polish these materials to an adequate optical surface finish. The discs would chip at the edges and scratch during the final polishing. The Sandia material sent to an outside polishing firm was returned with an unsatisfactory polish. Honeywell was contacted concerning this problem and have confirmed that after repeated attempts they have not been able to polish the material. On our standard polishing method on samples of earlier Honeywell material we used diamond spray on tin laps. In the last few weeks, we achieved an adequate final polish on two pieces of the Honeywell PLZT. These pieces were initially polished with diamond spray on tin laps to the required thickness and parallism and were then polished to the required flatness and surface finish with a chemical polish on a pitch lap. This technique is currently being tried on the Opto-Ceram PLZT and initial results appear as good as for the Honeywell material.



A) COMPLETED 32 X 32 BDC WITH
ELEMENTS ON 254 μm CENTERS



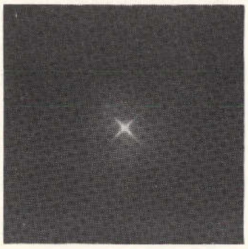
B) COMPLETED 32 X 32 ELEMENT BDC
WITH APERTURE MASK IN PLACE

87836-3

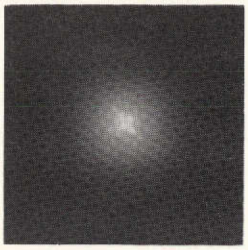
FIGURE 3-1. COMPLETED BLOCK DATA COMPOSERS

3.2 Spatial Filtering to Increase the Contrast Ratio

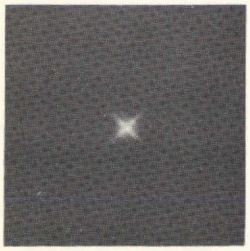
In the previous period, a 5 x 5 array was fabricated from Sandia material obtained a year ago. This array was a prototype for the material testing and evaluation program described in the last period report. This array was tested for electro-optic response by measuring the contrast ratio between the OFF (depoled) and ON (poled) states. It was observed that a great deal of the incident light was randomly scattered by the PLZT, causing the contrast ratio of the elements when operated in the strain-bias and differential modes to be just barely greater than 1 to 1. The intensity of the scattered light in the Fourier transform plane was greater than the intensity of the Fourier transform of the BDC. The Fourier transforms of other fabricated BDC's and also that of a 32 x 32 element photomask are shown in Figure 3-2. The randomly scattered light obscured the Fourier transform of BDC #31121 to the extent that a good extinction could not be obtained with this device when operated in the birefringent mode. The scattering was greater once the device had been switched than before testing began. This scattering is believed to depend upon the grain size of the material: PLZT with grain size, $G > 4.0\ \mu m$ scatters much more than for $G < 2.5\ \mu m$. The intensity or direction of the scattered light did not appear to depend upon the electrical state of the elements. A pinhole spatial filter in the transform plane was then placed to block out as much as the scattered light as possible while still passing enough of the Fourier transform to resolve the elements (i.e. to ensure that the optical system is not diffraction limited). In this manner a better extinction was obtained for the devices in the birefringent mode. The



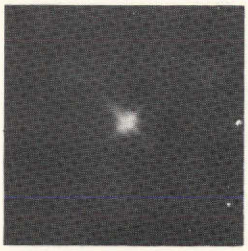
A) BDC 30305



C) BDC 31121



B) 32 X 32 ELEMENT MASK
(254 μm CENTERS)



D) BDC 31214

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FIGURE 3-2. FOURIER TRANSFORMS
(110 mm FOCAL LENGTH LENS)

optical set-up for the spatial filtering used is shown in Figure 3. 3. The pinhole is located in the Fourier transform plane of the first 100 mm focal length lens. The second lens re-imaged the matrix array and the third lens formed the Fourier transform of this image on a photoplastic storage array.

The contrast ratios of the elements in the 5 x 5 device mentioned above were measured in this system with a 400 μm pinhole filter. When the device was operated in the strain bias mode, the contrast ratios now ranged from 2.5 to 1 up to 5 to 1 with an average of 4.4 to 1. All other working BDC's were tested with this spatial filtering system, and where significant switchable birefringent was initially observed in the device (an optical retardation of greater than 100 nm) the contrast ratio was improved up to four times the unfiltered contrast ratio. This method appears similar to scattering mode operation but is a birefringent mode switching: removal or rotation of the analyzer will reduce the contrast ratio to 1 to 1.

The spatial filtering system shown in Figure 3-3 allows the filtering to be done before the hologram is recorded. However, for recording on an array of photoplastic recording elements, each recording element must have a corresponding pinhole in the first Fourier transform plane. This pinhole must be closely and accurately spaced from the pinholes for the other recording elements. Such a matrix of holes would allow enough scattered light through to defeat the original purpose. Theoretically, the spatial filtering could be done directly in the transform plane at the photoplastic recording array. This could be done by either of two methods: 1) narrow the diameter of the reference beam so that a hologram is recorded for only the desired central portion of the transform or 2) record a near Fourier transform with the full diameter reference beam and place a pinhole at the Fourier transform plane behind each of the recording elements. Either of

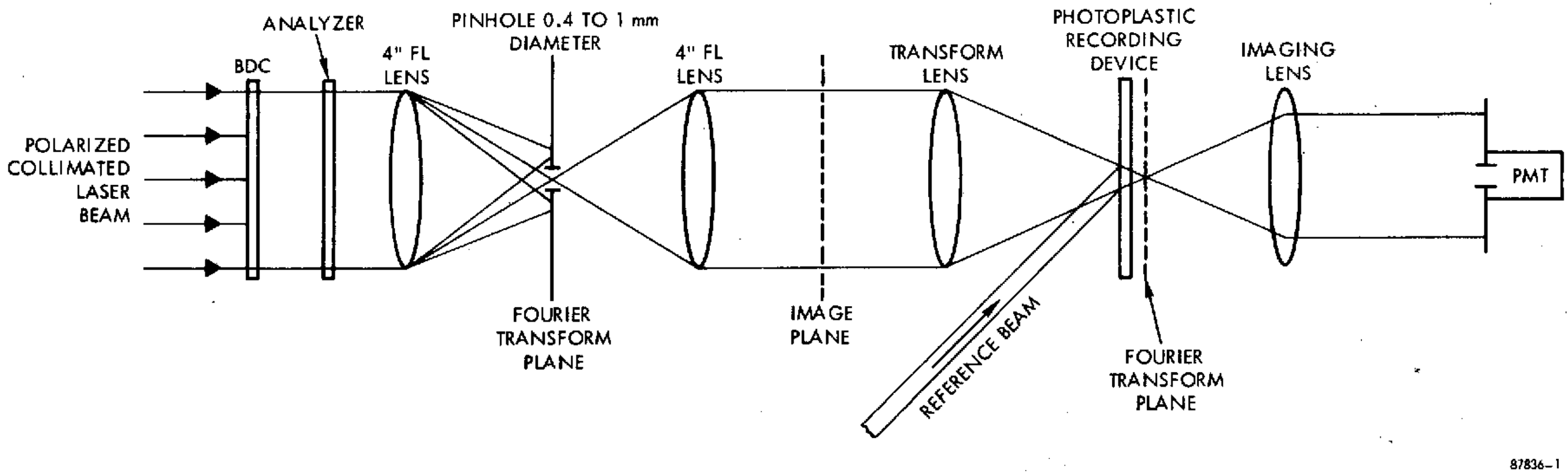

FIGURE 3.3 OPTICAL SYSTEM FOR SPATIAL FILTERING BEFORE RECORDING

these methods simplifies the optical system since the first two lens shown are not needed, and only the single long focal length lens remains. The first method calls for accurate positioning of the signal and reference beams at the surface of the recording elements. The second requires a matrix of pinholes to be fabricated as part of the photoplastic recording array. These two methods will be studied in the coming period to determine if they are compatible with the NASA test bed system.

3.3 Testing of 32 x 32 Element BDC's

Of the six 32 x 32 element BDC's on 254 μm centers completed for testing, four were made from Honeywell PLZT received during the previous contract[5], one was from Opto-Ceram received during the previous period[6] and one was from the recently received and polished Honeywell material. The first four Honeywell devices showed little or no switchable birefringence but a large amount of fixed scattering after they had been subjected to strain and to switching pulses. The thickness of the PLZT in these devices was greater than 175 μm because of the large amount of breakage encountered with thinner pieces. The Opto-Ceram material was polished to 150 μm. The BDC fabricated from this disc showed much less scattering (see Figure 3-2d) than the Honeywell material and also had significant switchable birefringence. The contrast ratio when operated in strain-bias (with spatial filtering) was between 10 and 15 to 1 for the majority of the elements but was not uniform over the array. The contrast ratio could only be maximized to the above level for approximately one quarter of the array surrounding the element being measured. Further, a polishing scratch developed into a crack as strain was applied, breaking contact to many of the bottom electrodes.

We searched the fabrication and test data of all the BDC's that have been made under this and previous contracts and found that all of the BDC's that have shown high contrast ratios in any of the birefringent modes were made from PLZT discs with thicknesses of ≤ 125 μm. A study of the literature showed that Smith measured the switchable strain in PLZT 7/65/35 and 7/63/37 as a function of polarization for thicker samples (250 to 400 μm)[7]. He predicted that thinner samples (< 150 μm) of these compositions would develop much greater strain differentials between the poled and depoled states than the thicker samples. According to our analysis of the differential phase mode[5], greater strain differentials yield greater index of refraction changes. When the PLZT is operated in the strain bias mode, greater switchable birefringence should result from greater strain differentials. For example, BDC # 30305, which worked very well in strain-bias and differential phase modes, had a PLZT thickness of 125 μm and with a grain size < 2.5 μm. It should be noted that the light scattering of this device is much less than those of BDC's made with recent materials. The Fourier transform of BDC #30305 is shown in Figure 3-2a. However, our records show that thinness of the PLZT alone is not a guarantee of high contrast ratio; many devices with thin PLZT showed no appreciable electro-optic response.

We attempted to polish the recently available PLZT to less than 125 μm and fabricate 32 x 32 element BDC's. The first BDC from this effort was made with a PLZT disc from Honeywell polished to a thickness of 115 μm. In initial tests, this device worked well in the edge-effect and strain-bias modes. At low levels of strain and switching voltage, significant switchable birefringence was observed. The device was tested with the spatial filtering system and patterns could be switched into the array. The contrast ratio of the elements was measured at between 3 and 5 to 1, and was relatively uniform over the entire array.

Additional experiments will be done to optimize the spatial filtering before any attempts are made to increase the strain and switching voltage applied to this BDC. Tests in the differential phase mode (i.e. without strain) will also be conducted prior to further testing in the strain bias mode.

The conclusions from these initial tests, the study of our test records, and the work by Smith are that BDC's with higher contrast ratio will require PLZT with thicknesses less than 125 μm, grain size < 2.0 μm and a composition that will maximize the strain differential between the poled and depoled states.

3.4 Plans for the Coming Period

1) Improve polishing techniques on new materials and polish discs to thicknesses less than 125 μm.
2) Fabricate 32 x 32 element BDC's with elements on 254 μm centers.
3) Test the fabricated BDC's in the strain-bias and differential phase modes.
4) Resume the electrical, electro-mechanical and electro-optic material testing program as polished samples become available.
5) Investigate further any spatial filtering techniques that will discriminate against the randomly scattered light.

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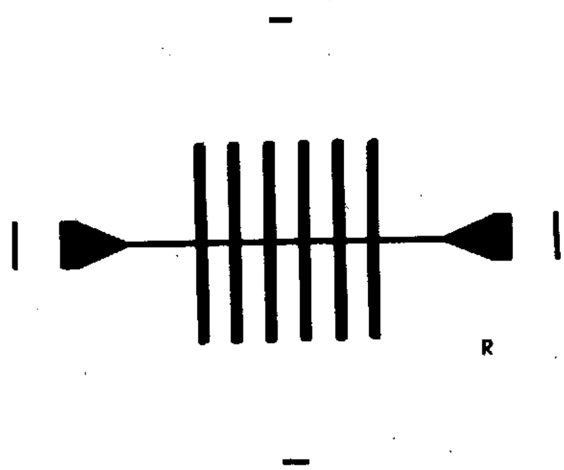
4

HOLOGRAM ARRAY

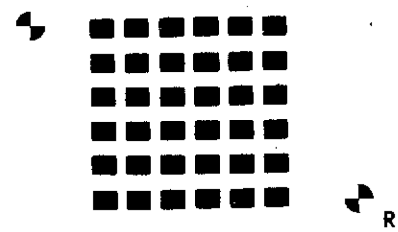
The hologram array consists of a glass plate with evaporated metallic leads to transparent conducting (SnO_2-In_2O_3) pads covered with a photoconductor and thermoplastic layer. An unbalance of forces between electrical charges on the top surface of the thermoplastic and the photoconductor deform the heated thermoplastic. A pattern of light, in this case a hologram of a bit pattern, determine the charge distribution in the photoconductor. The deformation remains fixed on cooling the thermoplastic, it can be erased by reheating to a higher temperature. The thermo plastic surface is charged from a transparent electrode close to and parallel to the thermoplastic.

4.1 Status of the Program

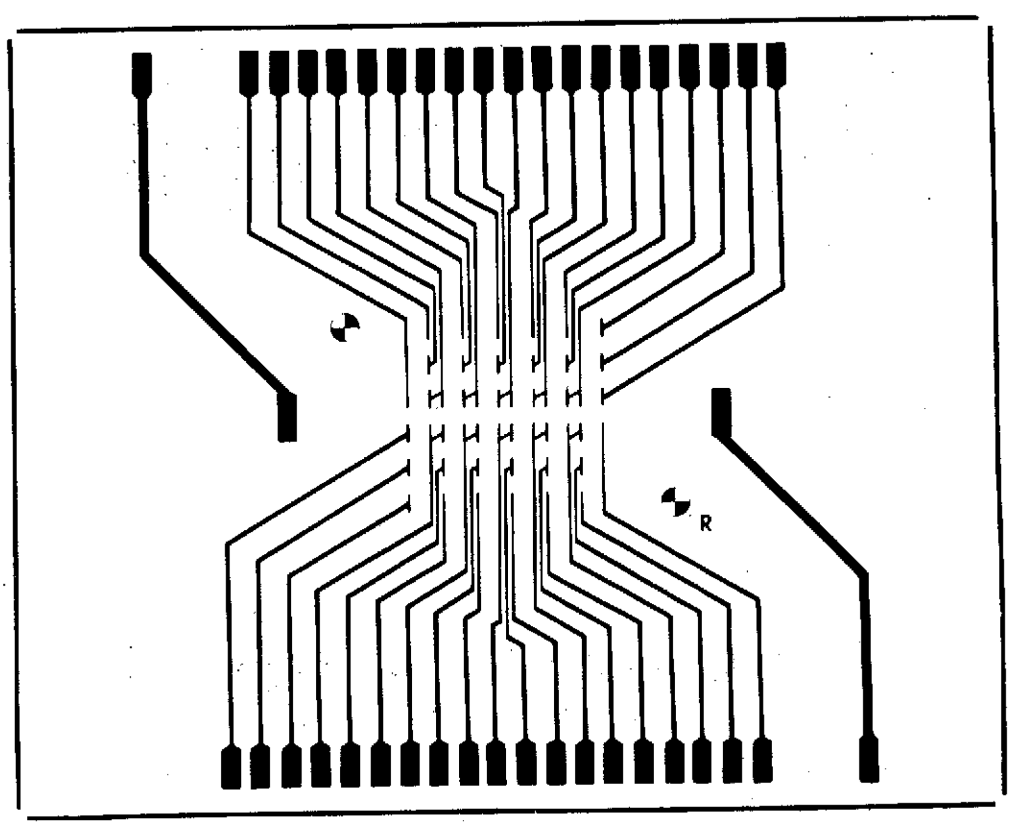
During this quarter we have completed a study of parallel plane charging. A 6 x 6 pad hologram array on 4.5 mm centers was constructed. This array permitted the study of various develop - erase cycles, adjust times and voltages, and determine failure modes. A reverse charge step was introduced into the process and a change was made in the method of heating. Various failure modes and changes made to correct them are discussed in Section 4.2. The data obtained is being incorporated into a 10 x 4 pad array and electronic package to drive it. A 10 x 4 array was chosen to facilitate the next step in the study, a 20 strip array using a 10.6 μm CO_2 laser for heating and a parallel plane for charging. This is discussed in Section 4.3.



A. ELECTRODE CONFIGURATION ON CHARGING PLATE



B. HEATING PADS ON ARRAY PLATE



C. ELECTRODE CONFIGURATION ON ARRAY PLATE

87812-2

FIGURE 4.1. MASKS FOR CHARGE PLANE AND ARRAY PLATE

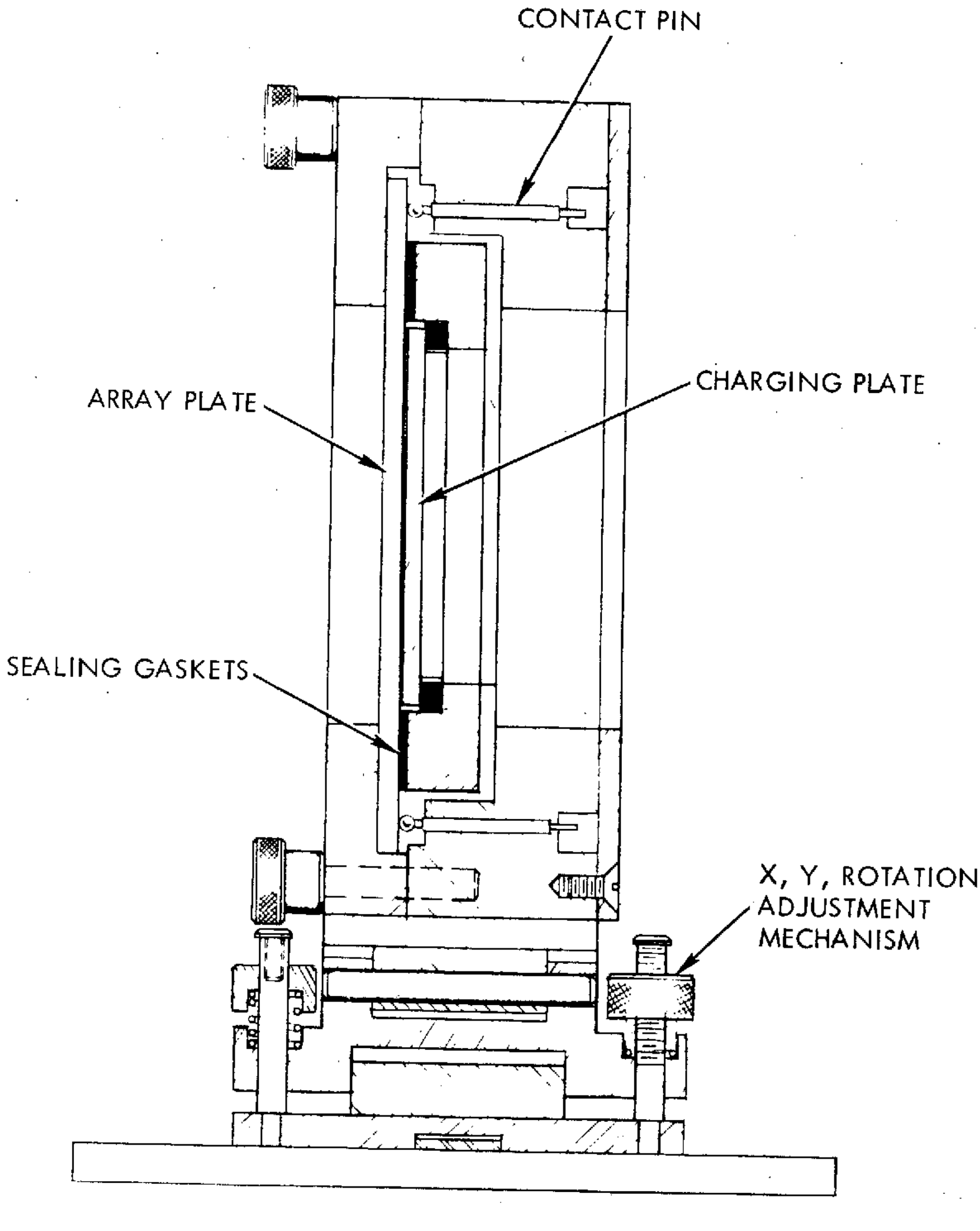


FIGURE 4.2. MODIFIED MOUNTING FIXTURE FOR HOLOGRAM ARRAY

4.2 Parallel Plane Charging Process

During the last period we developed a set of ground rules for design of the parallel plane charging electrodes. They prevented arcing which seriously limited the life of previous plates. The ground rules include using a 2 mil separation of the top electrode plane from the array, a + 600 v charge voltage, keeping the parallel plane electrodes from passing over the heating electrodes, the use of argon gas between the planes, and the elimination of dust and dirt from the thermoplastic layers. An array holder was modified to incorporate the new electrode configurations.

During this period we have tested the holder and various process cycles. Figure 4.1 shows a 6 x 6 pad array and charge plane. The actual size of the pads between electrodes is $2\frac{1}{2} \times 2\frac{1}{2}$ mm with a $1\frac{1}{2} \times 2$ mm active area under the charge plane finger. Figure 4.2 shows the modified holder. There has been no change in photoconductor or thermoplastic materials or the dipping process. A smaller pad size in the 6 x 6 array allowed a reduction in heat to develop and erase times. Heating times for develop and erase are given below:

	ARRAY	
	5 x 5	6 x 6
Pad Size	4 x 4 mm	$2\frac{1}{2} \times 2\frac{1}{2}$ mm
Time to develop	130 ms	40 ms
Time to erase	450 ms	160 ms

Individual pads of the 6 x 6 array were automatically sequenced thru expose-develop-erase cycles until the holographic image deteriorated. Such repeated use of the pads revealed the following modes of failure:

a) A build up of thermoplastic occurred on the charge plane after 25 to 100 cycles. This layer could be wiped off and the pad cycled 250 or more times before it required recleaning.

b) After 200 or more cycles the thermoplastic began to develop a blotchy appearance. This gradually increased as did the noise in the reconstructed hologram.

c) After 1000 cycles a gradual thinning of the thermoplastic layer was observed. Since the initial thickness of the thermoplastic is selected to maximize the diffraction efficiency and signal-to-noise ratio, this thinning is responsible for a reduction in these parameters.

d) After 1000 cycles, a gradual migration and buildup of thermoplastic was observed at the negative heating electrode.

While each of the above failure modes was observed under different test conditions they are obviously related. For example, the gradual thinning of the thermoplastic layer is caused in part by both the transport of material to the cover charge plane and the migration of the material to the heating electrode.

Attempts at first to solve the transport of thermoplastic across the 2 mil gap to the charge plane were frustrating. The obvious assumption, based on the experimental evidence, is that a light molecular weight fraction in the thermoplastic is evaporated on the charge plane during the erase cycle. Most of this fraction is removed from the layer during the initial cycles. If the charge-plane is then cleaned, very little additional build up should occur. Rather than accept a break in period as a solution to the problem we tried to prebake the undissolved photoplastic and also to pre-heat the dipped layer in a vacuum oven to remove the lighter fraction. Neither process improved the situation. At the same time we suspected that the residual positive charge left on the thermoplastic from the charge operation caused most of the migration to the negative electrode. Introducing a negative charge on the charge-plane before erasing reduced this migration and practically eliminated the evaporation to the charge plane. In fact neutralizing the residual positive charge on the upper thermoplastic surface greatly reduced all the above failure modes. The residual positive charge on the thermoplastic before erasure was confirmed by measurement. Reduction of the charge by applying a reduced negative charge on the charge plane was also confirmed. An electronic package has been designed to drive the hologram array. This includes shorter heating times, reverse charge before erase, and AC heating as an added precaution to prevent migration during development.

With confidence in parallel-plane charging at a satisfactory level, attention was directed to a 20 strip array with individual pad heating and parallel-plane charging. The requirement of a 20 x 20 array with individual develop and erase capabilities eliminates the possibility of resistance heating with their multitude of leads. A number of alternative possibilities were considered. The use of photoconductors as electric switches with the laser light to activate them, radio frequency heating, focused resistance heat source, and infra-red lasers, all are possible choices. The most feasible choice appears to be the IR laser. A possible configuration and one we are in the process of implementing, uses a glass back plate similar to our present one, an As_2S_3 window, and can be made to fit our present holder. The glass plate will have the usual SnO_2-In_2O_3 conducting ground plane plus the dip-coated photoconductor and thermoplastic layers. In this case, however, the usual heating electrodes will be absent. Two mils above the glass plate will be the charge plane, a SnO_2-In_2O_3 conducting layer on the As_2S_3. As_2S_3 is transparent to both visible and infra-red. The glass plate; however, absorbs infra-red as does the photoconductor. Full use of the laser heating would require a deflector system of some sort, mechanical or electro optical. For testing purposes we will move the hologram array on a micrometer track. A G.T.E. Sylvania 941P-7 Watt, 10.6 μm CO_2 laser has been selected. Heating times should be of the same order as in our present resistance heating process. The equipment and materials necessary to perform the above work is on order.

4.3 Future Plans

The 10 x 4 resistance heated array and the 20 strip laser heated array have the same pad recording area, about $1\frac{1}{2} \times 1\frac{1}{2}$ mm. Work on the 10 x 4 array will be continued to determine the minimum times for exposure, heating and cooling, and as a test vehicle for photoconductor and thermoplastic evaluation. When the electronic package and a 10 x 4 HOE is completed, the parts will be sent to NASA-Huntsville for demonstration on the test bed. Also during the next quarter the 20 strip CO_2 I.R. laser heated array will be set up on the Melbourne test bed. Initially the 20 strip array holder will be translated, keeping the signal, reference and IR beams fixed. The effectiveness of the laser heating, heating times, size and quality of recording holograms and their packing density will be determined.